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A STUDY ABOUT A RESISTIVE STEPPED TRANSDUCER USED FOR WATER LEVEL MEASUREMENT

Gabriel Nicolae POPA, Iosif POPA, Sorin Ioan DEACONU, Corina Daniela CUNȚAN

”Politehnica” University Timişoara, Faculty of Engineering Hunedoara, ROMANIA

Abstract:
In this work is analyzed a resistive stepped transducer used for water level measurement. For sending remote the information regarding the level, is used a level-frequency converter with an astable circuit with CD 4047. Experimentally it was determined the frequency modification from output depending on the water level in two situations: when the transducer's steps above the water are wet and when these steps are dry. In both situations is found a non-linear frequency modification, depending on the level. Were calculated the transducer's resistances in such way that the frequency will modify linearly with the level.

Keywords:
level, resistive transducers, level-frequency converters

1. INTRODUCTION

Electric measurement of the non-electric measures is applied on large scale in almost all domains. The advantages of the measuring electric methods against the non-electric methods are: high precision, high sensitivity, possibility for sending remote information, great adaptability, possibility and safety of recording, possibility to process the values obtained by measurement [1,2].

In practice, there are many conversion methods of the level of a liquid into an electric signal. When measuring the liquids level, there can be more measuring methods: with floating mechanism and electric transmission, impulse system for level's remote measurement, capacitive measuring methods, methods based on radioactive radiations, methods based on pressure measurement, methods based on mass measurement, resistive methods [3,4,5,6]. Level's measurement can be continuous or discontinuous [2].

2. RESISTIVE LEVEL TRANSDUCER WITH LEVEL-FREQUENCY CONVERTER

The resistive transducers are safe in operation and should achieve a conversion as good as possible of the level into another measure. An astable circuit alternates between two different output voltages. The output remains at each voltage level for a defined period of time. The astable circuit has two outputs, but no input [7].

The resistive level transducer with level-frequency converter is presented in fig.1.

The level-frequency conversion takes place in two steps: a level-resistance conversion achieved with the stepped level transducer itself (resistive transducer), followed by a resistance-frequency conversion made by a symmetric astable trigger circuit.

The integrated circuit CD 4047 is capable of operating in either the monostable or astable mode. It requires an external capacitor (between pins 1 and 3) and an external resistor (between pins 2 and 3) to determine the output pulse width in the monostable mode, and the output frequency in the astable mode. Astable operation is enabled by a high level or low level on the astable input. The output frequency, at 50% duty cycle, is determined by the timing components [7]. Features like astable circuit of CD 4047 [8]:

- wide supply voltage range: 3 ÷ 15 V;
- low power TTL compatibility;
- free-running or gatable operating modes;
- 50% duty cycle;
- good astable frequency stability:
  - typical=±2%+0.03%/^{o}C at 100 kHz, U_s=10 V;
  - frequency=±0.5%+0.015%/^{o}C at 10 kHz, U_s=10 V.

The astable trigger circuit has the integrated circuit CD 4047, the capacitance C and the transducer's resistors (R_1÷R_{10}). The resistive transducer is formed by putting in serial the resistances R_1÷R_{10} (the steps of the transducer's resistances). By increasing the level, are short-circuited, in order, the resistances R_1, R_2, ..., R_{10}. The modification of the equivalent resistance from the transistors' bases leads to the frequency modification of the voltage U_{out}. For the symmetric astable circuit, the output signal's frequency is [8]:

$$f = \frac{1}{4.4 \cdot R \cdot C} \tag{1}$$

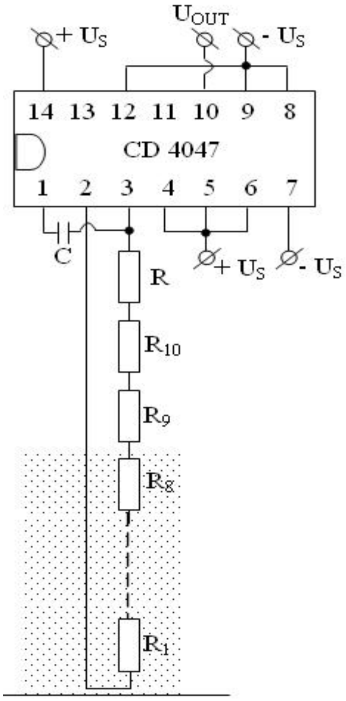

Figure 1. Resistive level transducer with level-frequency converter

Its are chosen the transducer's resistances $R_1 = R_2 ... = R_{10} = 18$ kΩ. It is notice in fig.1, that $R_{CB}=R_{23}$, the resistance between the pins 2 and 3 of CD 4047 (the resistance of transducer).

The transducer's resistances were introduced in plastic boxes with Φ 22 mm diameter and 30 mm length, and the boxes were filled with electrical insulating paste. The boxes where mounted on a stainless steel support. The transducer has the active length of 1 m, and the distance between two successive resistances is 10 cm. The resistances are serial, with tinned copper plates with the surface of 12.5 cm^2 and the distance against the metallic support of 1 cm (distance between plates). The resistive level transducer with level-frequency converter was practically tested into a tank of which principle diagram is presented in fig.3. In fig.2: 1 – tank, 2 – filler funnel, 3 – filler tap, 4 – tube scaled in level units, 5 – drain tap, 6 – vent valve, 7 – support. In fig. 3 is the resistive transducer used in experiments.

To determine the frequency's real values depending on resistivity, should be determined the resistivity of the water used in experiments. In order to determine the resistivity of the potable water, it was used the volt-ammeter measuring method of the resistance. This method was used in alternate current to avoid the water's electric polarization phenomena. It was used an experimental device formed by two plane-parallel plates of surface S_1=20.8 cm^2 and distance between them of l_1=1.8 cm in upstream (fig.4) and downstream (fig.5) montage.

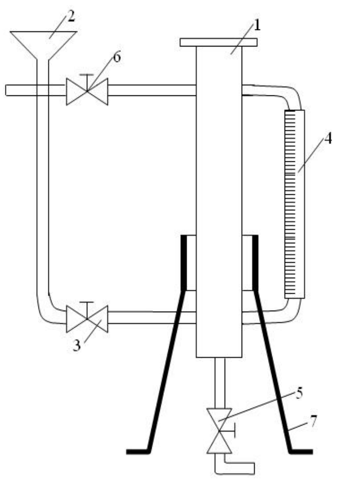

Figure 2. The tank used for checking the resistive transducer

Figure 3. The resistive transducer used in experiments

The potable water resistances and resistivities for the upstream montage are determined with the relations:

$$R = \frac{U}{I} - R_{mA} \tag{2}$$

$$\rho = \left(\frac{U}{I} - R_{mA}\right) \cdot \frac{S_1}{l_1} \tag{3}$$

and for the downstream montage with:

$$R = \frac{U}{I \cdot R_v - U} R_v \tag{4}$$

$$\rho = \frac{U}{I \cdot R_v - U} R_v \cdot \frac{S_1}{l_1} \tag{5}$$

For the measuring instruments, R_v=1000Ω and R_{mA}=275Ω. The measurement results and the calculation of resistances and resistivities are given in table 1. From table 1 it results the average value for the potable water resistivity used in experiments: ρ_{avg}=52.35 Ω·m.

By measuring the resistances, the transducer has the following values for the resistance steps (fig.1,3): R_1=17.66 kΩ; R_2=17.5 kΩ; R_3=17.3 kΩ; R_4=16.96 kΩ; R_5=17.12 kΩ; R_6=16.98 kΩ; R_7=17.26 kΩ; R_8=17.5 kΩ; R_9=17.08 kΩ; R_{10}=17.32 kΩ and R_B=121.4 kΩ and C=101 pF.

The measurements of the signal's frequencies from the circuit's output were made with the TRMS Protek 506 multimeter. To verify the operation of the transducer from fig.1, was measured the output frequency, by short-circuiting the resistance steps.

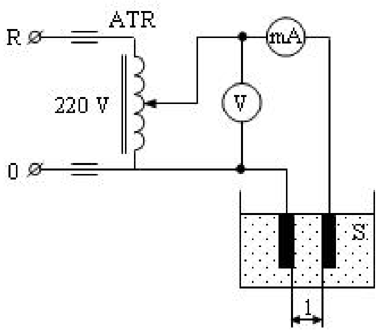

Figure 4. The volt-ammeter method – upstream montage

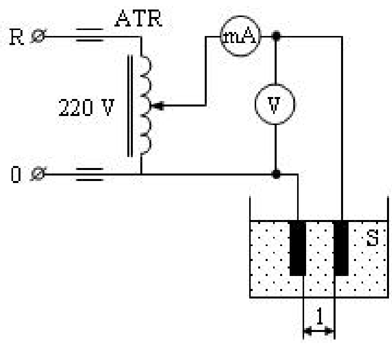

Figure 5. The volt-ammeter method – downstream montage

Table 1. Determination of water's resistivity

Electric Measures	Montage type						Average value
	upstream			downstream			
	1	2	3	1	2	3	
U [V]	0.52	0.88	1.75	0.26	0.63	0.75	-
I [mA]	0.78	1.15	2.4	0.8	1.825	2.34	-
R [Ω]	391	493	453	482	524	470	468.8
ρ [Ω·m]	45.2	56.8	52.5	55.6	60.6	54.2	54
Electric Measures	Montage type						Average value
	upstream			downstream			
	1	2	3	1	2	3	
U [V]	0.35	0.7	1.38	0.32	0.43	0.74	-
I [mA]	0.47	0.97	1.95	1.08	1.42	2.45	-
R [Ω]	469	445	435	421	434	433	439.5
ρ [Ω·m]	54.2	51.5	50	48.7	50	50	50.7

If the tank is empty (h=0), the transducer has all the resistances:

$$R_t=R_{1\text{-}10}=R_1+R_2+...+R_{10} \tag{6}$$

If the tank has h=10cm of water, then the transducer's resistance is:

$$R_t=R_{2\text{-}10}=R_2+R_3+...+R_{10} \tag{7}$$

For h=90 cm, the transducer's resistance is:

$$R_t=R_{10\text{-}10}=R_{10} \tag{8}$$

For h=100 cm, the transducer's resistance is R_t=0.

For U_s=10V it was made a comparative analysis in table 2, between the frequency's calculated values (f_c) and the measured ones (f_m). It was determined the relative error with:

$$\varepsilon_r = \frac{f_c - f_m}{f_m} \cdot 100 \ [\%] \tag{9}$$

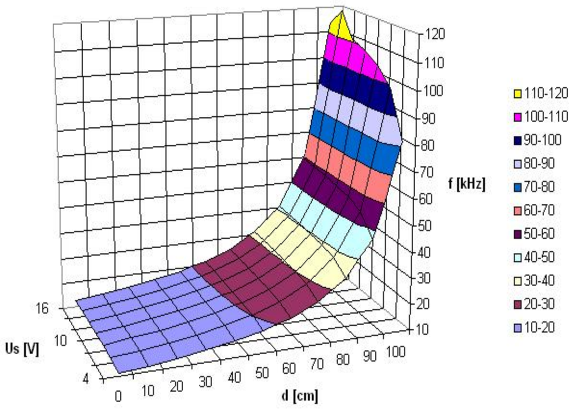

Figure 6. The output signal's measured frequency (f) depending on level (h) and supply voltage (U_s), when the resistance steps are short-circuited

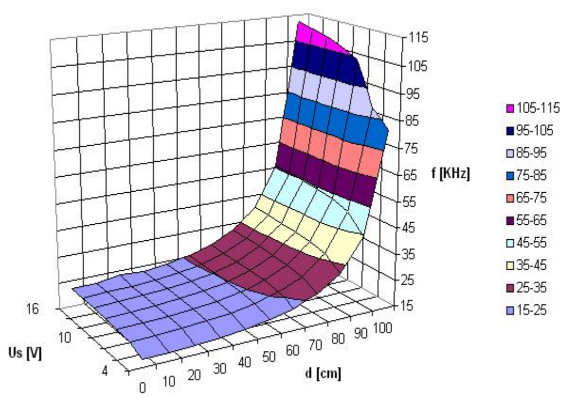

Figure 7. The output signal's measured frequency (f) depending on level (h) and supply voltage (U_s), when the transducer is introduced in water, the resistance steps above the water being wet

From table 2, one can notice that, for the h=0-100 cm ε_r is acceptable, that validate the calculate frequency with (1).

In fig.7 and 8 were measured the circuit's output signal frequencies depending on h and U_s, in two situations:

- at a rapid water level modification, the superior resistance steps remain wet (fig.7);
- at a slow water level modification, the superior resistance steps having time to dry-up (fig.8).

The first situation is rarely met in practice than the second situation.

Table 2. The calculated and measured frequency depending on the level (by short-circuiting the steps) U_s=10V

h [cm]	0	10	20	30	40	50
f_c [kHz]	11.8	13.04	14.46	16.27	18.55	21.6
f_m [kHz]	12.39	13.44	14.73	16.32	18.34	21.04
ε_r [%]	-6.2	-4.66	-3.34	-1.99	-0.57	0.71
h [cm]	60	70	80	90	100	
f_c [kHz]	25.81	32.18	42.92	63.67	124.87	
f_m [kHz]	24.67	30.39	39.78	57.61	108.7	
ε_r [%]	2.01	3.41	5.01	7.08	9.73	

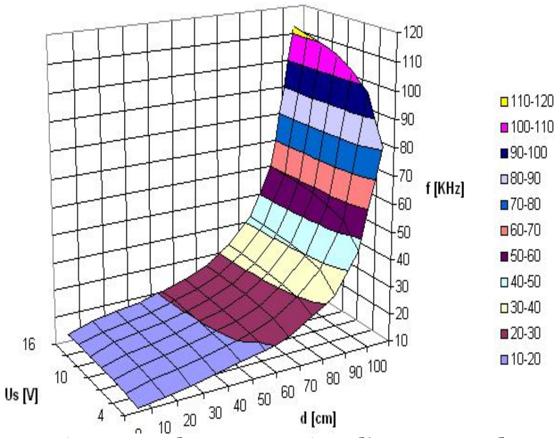

Figure 8. The output signal's measured frequency (f) depending on height (h) and supply voltage (U_s), when the transducer is introduced in water, the resistance steps above the water being dry

For determining the signal's frequency depending on the transducer's resistance, it should be used the transducer's electric model in real operation conditions (is taken into account the water resistance between the transducer's plates). Further, the resistance steps above the water are assumed to be dry. The resistance between the plates, when the water is at their mid-height, is R_s:

$$R_s = \rho \cdot \frac{l}{\frac{S}{2}} \tag{10}$$

where ρ is the water resistivity, l is the distance between the transducer's plates, and S is the common surface between the plates, when the water is at their mid-height. With the calculated data (ρ) and measured data (l, S) is obtained R_s=1.68 kΩ. For h=0 (fig.1), the transducer's resistance is given by (fig.9):

$$R_{CB0} = \sum_{i=1}^{10} R_i \tag{11}$$

With the resistances' measured values is obtained $R_t=R_{CB0}$=294.08 kΩ. For h=10 cm, in situation when the water is at the mid-height of the plate for the first step, the electric model of the transducer's resistance is $R_t=R_{CB1}$ is presented in fig.10.

$$R_{CB1} = \sum_{i=2}^{10} R_i + \frac{R_1 \cdot R_s}{R_1 + R_s} \tag{12}$$

Is obtained R_{CB1}=277.95 kΩ. For h=20 cm, in situation when the water is at the mid-height of the plate for the first step, the electric model of the transducer's resistance is $R_t=R_{CB2}$ is presented in fig.11. Step 1 is completely under water, the metallic plates being completely covered. Their equivalent resistance is R_s/2.

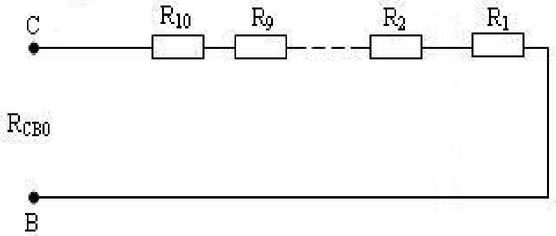

Figure 9. Electric model for h=0

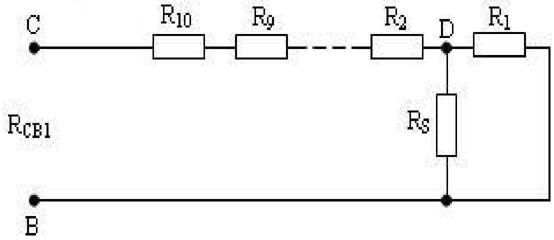

Figure 10. Electric model for h=10cm

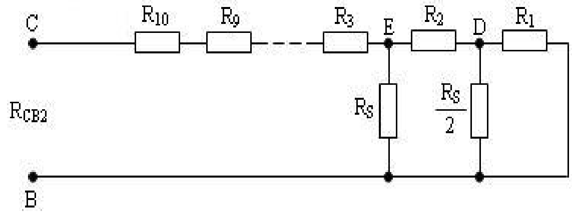

Figure 11. Electric model for h=20cm

$$R_{CB2} = \sum_{i=3}^{10} R_i + \frac{\left(\frac{R_1 \cdot R_s}{2 \cdot R_1 + R_s} + R_2\right) \cdot R_s}{\frac{R_1 \cdot R_s}{2 \cdot R_1 + R_s} + R_2 + R_s} \tag{13}$$

Is obtained R_{CB2}=260.45 kΩ. Calculating little by little, are determined also the other values of the resistances for the other values of the water height (table 3). In table 3, f_m is the output signal's frequency when U_s=10V, and the resistance steps above the water are dry.

Table 3. The measured and calculated frequency depending on R_{CBi}

h [cm]	0	10	20	30	40	50
R_{CBi} [kΩ]	190.7	99.69	69.1	52.87	42.82	35.98
f_c [kHz]	12.58	22.57	32.56	42.55	52.54	62.54
h [cm]	60	70	80	90	100	
R_{CBi} [kΩ]	31.02	27.26	24.32	21.95	20	
f_c [kHz]	72.53	82.52	92.51	102.5	112.5	

3. LINEARIZATION OF THE CHARACTERISTIC OF THE RESISTIVE LEVEL TRANSDUCER WITH LEVEL-FREQUENCY CONVERTER

The characteristics from fig.7 and 8 are non-linear. The issue is to determine the values of the transducer's resistances in such way that the frequency indication depending on level to be linear. Is imposed the modification of the output signal's frequency between 12.58 kHz and 112.5 kHz, with 9.992 kHz step. From (1) is calculated the resistance depending on frequency:

$$R = \frac{1}{4.4 \cdot f \cdot C} \tag{14}$$

This frequency interval is divided to the number of resistance steps of the transducer, and then, by (14) are determined the resistances R_{CBi} from the transducer's electric model (table 4). Further, is considered that when the water is at a certain level, the water covers half of the surface S common between the two plates, and the water's equivalent resistance is R_S. If the plates are completely covered, then the water's equivalent resistance is $R_S/2$. For h=0 (fig.9):

$$R_{CB0} = \sum_{i=1}^{10} R_i \tag{15}$$

From (15), it results R_1=92.66 kΩ. For h=10 cm (fig.10):

$$R_{CB1} = \sum_{i=2}^{10} R_i + \frac{R_1 \cdot R_S}{R_1 + R_S} \tag{16}$$

By making the difference between R_{CB1} (16) with R_{CB0} (15), is obtained:

$$R_{CB1} - R_{CB0} = R_1 - \frac{R_1 \cdot R_S}{R_1 + R_S} \tag{17}$$

From (27), R_2=30.53 kΩ.

Proceeding similarly by achieving the transducer's electric model for each case in part, are obtained also the other resistance values which will determine a linear modification of the frequency depending on level.

Table 4. The resistances calculated and used in experiments for the circuit from fig.2 – linearized characteristic

Resistance	R_1	R_2	R_3	R_4	R_5
calculated [kΩ]	92.66	30.53	16.16	9.98	6.76
measured [kΩ]	93	30.6	16.18	9.95	6.7
Resistance	R_6	R_7	R_8	R_9	R_{10}
calculated [kΩ]	4.68	3.69	2.87	2.3	1.88
measured [kΩ]	4.65	3.7	2.87	2.3	1.89

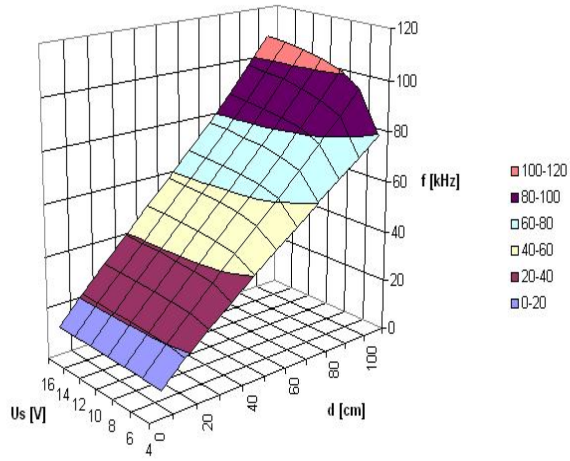

Figure 12. The measured frequency of the output signal (f) depending on level (h) and supply voltage (U_s) after liniarization

4. CONCLUSION

It was analyzed a 10-step resistive transducer connected to an astable trigger circuit in such way to achieve the level-frequency conversion. The condition (wet or dry) of the resistances above the water influences the transducer's operation. For equal values of the transducer's resistance steps, the frequency depends non-linear on the water level. Were analytically determined the transducer's resistance steps in such way that the frequency to depend linearly on the level. The transducer can be used in applications where the level does not fluctuate (does not modify up and down with high speed) in order that the insulating support of the resistances above the water to have time to dry-up. Can be also used other electronic circuits attached to this type of transducer, that should achieve the level-frequency conversion.

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